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Abstract

Extensive use of corn coproducts in swine diets increases the concentration of dietary fiber, raising concerns on energy and nutrient digestibility and, ultimately, pig performance. A digestion trial was conducted to determine the effect of increasing levels of insoluble-low fermentable fiber from corn in the diet, using corn bran with solubles (CBS) from the corn-ethanol distillation industry, on digestibility of energy, fiber, and AA, and hindgut fermentation of fiber in diets fed to growing pigs. Fifteen growing pigs (BW = 28.7 kg) arranged in a 3-period incomplete block design and fitted with a T-cannula in the distal ileum were provided 5 diets ($n = 9$) containing either a corn-casein basal or the basal diet with 10, 20, 30, or 40% CBS. Fecal and ileal digesta samples were collected. Two subsequent 28-d growth trials determined the effects of increasing dietary fiber from CBS in 2 sets of 7 diets formulated either with declining (growing phase: 2,387 to 2,133 kcal NE/kg; finishing phase: 2,499 to 2,209 kcal NE/kg) or constant dietary NE (growing phase \approx 2,390 kcal NE/kg; finishing phase \approx 2,500 kcal NE/kg) on growth performance and apparent total tract digestibility (ATTD) of energy in 70 growing (BW = 48.9 kg; $n = 10$ per diet) and 70 finishing (BW = 102.0 kg; $n = 10$) pigs. Results indicated that increasing fiber from corn lowered ($P < 0.01$) the apparent ileal digestibility of all indispensable amino acids except Arg, GE, DM, and CP but not NDF or total dietary fiber (TDF). Increased fiber from corn also reduced ATTD of GE, DM, CP, NDF, and TDF ($P < 0.01$). Increasing fiber with declining diet NE lowered BW, ADG, and G:F ($P < 0.05$) in growing and in finishing pigs. When NE was held constant, as fiber increased, BW and ADG were unaffected in growing and finishing pigs, and G:F was unaffected in finishing pigs but improved in growing pigs ($P < 0.05$) with increasing dietary fiber. In both growing and finishing pigs, ADFI was unaffected by the increased fiber from corn, regardless of the NE content of diets. In conclusion, the dietary level of insoluble-low fermentable dietary fiber from corn origin decreased the digestibility of dietary AA, and the ability of the growing pig to ferment corn dietary fiber. In spite of the reduction in digestibility of energy and nutrients with insoluble-low fermentable fiber level from corn, growth performance was not impaired when the energy supply is adequately balanced in the diet using the NE system.

Keywords

amino acids, digestibility, energy, fiber, hindgut fermentation, pig

Disciplines

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Effect of insoluble-low fermentable fiber from corn-ethanol distillation origin on energy, fiber, and amino acid digestibility, hindgut degradability of fiber, and growth performance of pigs¹

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ABSTRACT: Extensive use of corn coproducts in swine diets increases the concentration of dietary fiber, raising concerns on energy and nutrient digestibility and, ultimately, pig performance. A digestion trial was conducted to determine the effect of increasing levels of insoluble-low fermentable fiber from corn in the diet, using corn bran with solubles (CBS) from the corn-ethanol distillation industry, on digestibility of energy, fiber, and AA, and hindgut fermentation of fiber in diets fed to growing pigs. Fifteen growing pigs (BW = 28.7 kg) arranged in a 3-period incomplete block design and fitted with a T-cannula in the distal ileum were provided 5 diets ($n = 9$) containing either a corn-casein basal or the basal diet with 10, 20, 30, or 40% CBS. Fecal and ileal digesta samples were collected. Two subsequent 28-d growth trials determined the effects of increasing dietary fiber from CBS in 2 sets of 7 diets formulated either with declining (growing phase: 2,387 to 2,133 kcal NE/kg; finishing phase: 2,499 to 2,209 kcal NE/kg) or constant dietary NE (growing phase \approx 2,390 kcal NE/kg; finishing phase \approx 2,500 kcal NE/kg) on growth performance and apparent total tract digestibility (ATTD) of energy in 70 growing (BW = 48.9 kg;

$n = 10$ per diet) and 70 finishing (BW = 102.0 kg; $n = 10$) pigs. Results indicated that increasing fiber from corn lowered ($P < 0.01$) the apparent ileal digestibility of all indispensable amino acids except Arg, GE, DM, and CP but not NDF or total dietary fiber (TDF). Increased fiber from corn also reduced ATTD of GE, DM, CP, NDF, and TDF ($P < 0.01$). Increasing fiber with declining diet NE lowered BW, ADG, and G:F ($P < 0.05$) in growing and in finishing pigs. When NE was held constant, as fiber increased, BW and ADG were unaffected in growing and finishing pigs, and G:F was unaffected in finishing pigs but improved in growing pigs ($P < 0.05$) with increasing dietary fiber. In both growing and finishing pigs, ADFI was unaffected by the increased fiber from corn, regardless of the NE content of diets. In conclusion, the dietary level of insoluble-low fermentable dietary fiber from corn origin decreased the digestibility of dietary AA, and the ability of the growing pig to ferment corn dietary fiber. In spite of the reduction in digestibility of energy and nutrients with insoluble-low fermentable fiber level from corn, growth performance was not impaired when the energy supply is adequately balanced in the diet using the NE system.

Key words: amino acids, digestibility, energy, fiber, hindgut fermentation, pig

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INTRODUCTION

Corn and its coproducts are used extensively in swine diets because of their availability, cost, and nutrient composition. The inclusion of corn distillers dried grains with solubles (DDGS) increases the concentration of dietary fiber in corn-soybean diets as a result of its high fiber content (NRC, 2012). Fiber in corn and its coproducts is largely insoluble because of its content of arabinoxylans, cellulose, and lignin and is mostly resistant to hindgut fermentation (Bach

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Knudsen, 1997; Choct, 2002). Addition of insoluble fiber to swine diets may also decrease the digestibility of dietary energy, Lys, and fiber (Noblet and Le Goff, 2001; Urriola and Stein, 2010). The inclusion of corn DDGS in commercial swine diets has been reported to decrease ADG and ADFI although this may be a reflection of an incorrect nutrient profile used in diet formulation (Whitney et al., 2006; Linneen et al., 2008).

The apparent ileal digestibility (**AID**) and apparent total tract digestibility (**ATTD**) of fiber is, however, different among sources of corn DDGS (Urriola et al., 2010), which may contribute to differences in digestibility of energy in DDGS and subsequently in diets containing DDGS. Corn bran with solubles (**CBS**), obtained after adding solubles remaining from the corn-ethanol distillation process to corn bran, is a good research model to evaluate the effects of corn fiber in swine diets because it has a lower concentration of starch and a greater concentration of fat and fiber than in whole corn grain (Bach Knudsen, 1997). The first objective of this study was to test the hypothesis that inclusion of insoluble-low fermentable fiber from corn decreases the digestibility of energy, fiber, and AA and reduces the hindgut fermentation of fiber in growing pigs. A second objective was to test the hypothesis that the increase of dietary fiber from corn, in diets with declining or constant NE, reduces growth performance and ATTD of energy in growing and finishing pigs.

MATERIALS AND METHODS

The experimental protocols for the digestion and growth trials were reviewed and approved by the Institutional Animal Care and Use Committee at Iowa State University.

Digestion Trial

Fifteen growing barrows (progeny of 337 sires × C-22 dams; PIC, Hendersonville, TN) were housed in individual pens of 1.2 by 1.2 m equipped with a feeder, a cup waterer, and a half concrete slatted floor surface in an environmentally controlled building. All pigs were surgically fitted with a T-cannula in the distal ileum following procedures described by Stein et al. (1998). Pigs were allowed to recover from surgery for 7 d and fed a standard corn-soybean meal diet ad libitum.

Dietary treatments included a corn-casein basal diet that was formulated to meet the nutrient requirements of growing pigs, as recommended by the NRC (1998). Four additional dietary treatments were obtained by replacing the basal diet with CBS (Table 1) in 4 equally spaced steps: 10, 20, 30, and 40% (Table 2). Because of the high total dietary fiber (**TDF**) concentration in

Table 1. Analyzed composition of corn bran with solubles (as-fed basis)

Composition	Corn bran with solubles ¹
DM, %	95.27
GE, kcal/kg	4,581
Ether extract, %	8.30
Starch, %	24.07
ADF, %	5.89
NDF, %	22.74
TDF, ² %	25.15
CP, %	13.02
Indispensable AA, %	
Arg	0.78
His	0.53
Ile	0.67
Leu	2.00
Lys	0.65
Met	0.31
Phe	0.81
Thr	0.70
Trp	0.12
Val	0.88
Dispensable AA, %	
Ala	1.28
Asp	1.19
Cys	0.35
Glu	2.82
Gly	0.71
Pro	1.38
Ser	0.83
Tyr	0.61
All AA, %	16.62

¹Poet Nutrition, Glenville, MN.

²TDF = total dietary fiber.

CBS, the resulting TDF content of dietary treatments was 7.3, 8.7, 9.1, 11.4, and 14.7% (as-fed basis). Corn or CBS were the only sources of dietary fiber, and standardized ileal digestible (**SID**) Lys:ME was maintained at 2.6 g/Mcal ME across treatments. Diets also contained TiO₂ at 0.45% (as-fed basis) as an inert marker. The portion of the diet including limestone, monocalcium phosphate, L-Trp, TiO₂, vitamin and trace mineral premixes, and zinc sulfate, and NaCl was maintained constant (3.8%) across all experimental diets.

After recovery from surgery, pigs were weighed (initial BW = 28.7 ± 2.1 kg) and randomly allotted to 5 dietary treatment groups in a 3-period incomplete block design, totaling 9 experimental units per treatment. Pigs did not repeat dietary treatments across periods. Each collection period involved 9 d of adaptation to dietary treatments followed by 2 d of feces subsample collection and 3 d of ileal digesta subsample collection.

All pigs received the same daily amount of feed, which was provided at a level of approximately 90% of predicted

Table 2. Ingredient and composition (as-fed basis) of experimental diets for the digestion trial

Item	CBS, ¹ %				
	0	10	20	30	40
Ingredient, %					
Ground corn	84.00	75.30	66.50	57.80	49.10
Corn bran	—	10.00	20.00	30.00	40.00
Casein	10.00	9.00	7.90	6.90	5.80
Soybean oil	2.20	2.00	1.70	1.50	1.30
Limestone	1.24	1.24	1.24	1.24	1.24
Monocalcium phosphate	1.20	1.20	1.20	1.20	1.20
L-Trp	0.01	0.01	0.01	0.01	0.01
Titanium dioxide	0.45	0.45	0.45	0.45	0.45
Vitamin premix ²	0.15	0.15	0.15	0.15	0.15
Trace mineral premix ³	0.10	0.10	0.10	0.10	0.10
Zinc oxide ⁴	0.05	0.05	0.05	0.05	0.05
NaCl	0.60	0.60	0.60	0.60	0.60
Energy and nutrients ⁵					
GE, kcal/kg	3,853	3,884	3,969	4,081	4,140
ME, kcal/kg	3,411	3,229	3,046	2,864	2,681
NE, kcal/kg	2,393	2,273	2,153	2,033	1,914
Ether extract, %	4.04	4.69	4.84	5.50	6.08
Starch, %	57.07	54.11	49.75	46.21	44.07
ADF, %	2.35	2.64	2.93	3.22	3.51
NDF, %	6.76	8.56	10.79	11.32	14.01
TDF, ⁶ %	7.27	8.69	9.11	11.41	14.73
CP, %	15.8	15.7	15.6	15.5	15.3
SID ⁷ Lys, %	0.91	0.86	0.81	0.76	0.71
Met + Cys, %	0.44	0.41	0.46	0.51	0.53
Thr, %	0.54	0.49	0.55	0.59	0.62
Trp, %	0.16	0.16	0.16	0.17	0.15

¹CBS = corn bran with solubles; 0 = basal diet; 10 = diet containing 10% of CBS; 20 = diet containing 20% of CBS; 30 = diet containing 30% of CBS; 40 = diet containing 40% of CBS.

²Provided per kilogram of complete diet: 6,614 IU of vitamin A; 827 IU of vitamin D; 26 IU of vitamin E; 2.6 mg of vitamin K; 29.8 mg of niacin; 16.5 mg of pantothenic acid; 5.0 mg of riboflavin; 0.023 mg of vitamin B₁₂.

³Provided per kilogram of complete diet: Fe, 165 mg as FeSO₄; Mn, 39 mg as MnSO₄; Cu, 17 mg as CuSO₄; I, 0.3 mg as Ca(IO₃)₂; Se, 0.3 mg as Na₂SeO₃.

⁴Zinc oxide = 72% Zn.

⁵Values for ME and standardized ileal digestible Lys were calculated from NRC (1998). Values for NE of diets were calculated from Sauvant et al. (2004); all other values were analyzed.

⁶TDF = total dietary fiber.

⁷SID = standardized ileal digestible.

ad libitum intake of the basal diet. Ad libitum intake was calculated as DE intake (kcal/d) = $13.162 \times (1 - e^{-0.0176 \times BW})$, where BW was average BW (NRC, 1998).

To convert ad libitum DE intake to ME units, the efficiency of use of dietary DE for ME was assumed to be 0.96 (Noblet et al., 1994) with the ME of the basal diet estimated to be 3,411 kcal/kg. Feed intake was then adjusted to 90% of this predicted value, and all pigs were offered the same daily amount. During the trial the daily feed allowance was divided into 2 equal meals provided at 0700 and 1600 h. At the end

of each collection period all animals were weighed and daily feed allowance was adjusted.

After 9 d adaptation to the diet, feces were collected via grab sampling on d 10 and 11 and stored at -20°C. On d 12, 13, and 14, ileal digesta samples were collected for 8 h and stored following the procedures for collection and storage of ileal digesta reported by Cervantes-Pahm and Stein (2008).

At the conclusion of each experimental period, frozen ileal and fecal samples were allowed to thaw at room temperature and pooled within animal, with a subsample collected for chemical analysis. Ileal subsamples were lyophilized before chemical analysis. Fecal subsamples were oven dried in a convection oven at 65°C to constant weight (Jacobs et al., 2011). After drying, ileal and fecal subsamples were ground through a 1-mm screen before chemical analysis.

Samples of CBS, diets, ileal digesta, and feces were analyzed for DM (Method 930.15; AOAC, 2007), ether extract (EE; Method 920.39; AOAC, 2007), starch (ST; Method 996.11; AOAC, 2007), ADF (Goering and Van Soest, 1970), NDF (van Soest and Robertson, 1979), TDF (Method 985.29; AOAC, 2007), and N (Method 968.06; AOAC, 1990). Crude protein was calculated as $N \times 6.25$ and Gly was used as the standard for calibration. Samples were also analyzed for GE by bomb calorimetry (Parr 6200 calorimeter; Parr Instruments Co., Moline, IL) and benzoic acid was used as the standard for calibration. Samples of CBS, diets, feed ingredients, and ileal digesta were analyzed for AA with an AA analyzer (Model No. L8800; Hitachi High Technologies America Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6 N HCl for 24 h at 110°C (Method 982.30 E[a]; AOAC, 2007). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (Method 982.30 E[c]; AOAC, 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (Method 982.30 E[c]; AOAC, 2007). Titanium dioxide concentrations of diets, ileal digesta, and fecal subsamples were determined according to the procedure of Leone (1973).

For each dietary treatment, the AID of GE, DM, N, AA, NDF, and TDF were calculated following the procedures outlined by Stein et al. (2007). The ATTD of GE, DM, NDF, and TDF in each diet were calculated following the procedures of Oresanya et al. (2008). The amount of dietary components reaching the terminal ileum and excreted in feces was calculated relative to the indigestible marker (TiO₂) as described by Urriola and Stein (2010). The net disappearance of DM, N, NDF, and TDF in the hindgut was calculated by subtracting the amount (g) of ileal digested dietary component from the amount (g) of total tract digested dietary component. Fermentation of energy was calculated by subtracting the amount

(kcal) of ileal digested energy from the amount (kcal) of total tract digested energy (Högberg and Lindberg, 2004).

Growth Trials

In two subsequent trials, in both the growing and the finishing phases, 35 barrows and 35 gilts (337 sires \times C-22 dams; PIC) were housed individually in pens of 1.2 \times 1.2 m equipped with a feeder, a cup waterer, and half concrete slatted floor surface. The average initial BW was 31.2 \pm 1.4 kg for growing and 85.4 \pm 4.7 kg for finishing pigs.

In each growth phase, pigs were allotted based on BW to 7 dietary treatments with 10 experimental units per treatment. In the 2 growth phases, treatments included a basal corn–soybean meal diet formulated to meet all nutrient requirements as recommended by the NRC (1998) and 6 experimental diets formulated with 3 levels of added CBS (7.5, 15, and 22.5% CBS for growing pigs or 8, 16, and 24% CBS for finishing pigs) with added soybean oil (SBO; 2, 4, or 6%, respectively) or without added SBO to create a set of treatments with a constant NE and another set of treatments with a declining NE as CBS increased (Tables 3 and 4). The maximum dietary inclusion level of CBS was selected to maintain constant NE with a maximum of 6% added fat. After establishing upper added CBS and fat levels, equally spaced intermediate levels were selected for both. The CBS used to increase the dietary fiber level came from the same batch as in the digestion trial. Net energy for diets was calculated based on ingredient composition libraries (Sauvant et al., 2004). Constant SID Lys:NE ratios (3.85 and 2.33 g/Mcal NE for growing and finishing pigs, respectively) were maintained across treatments. Diets were formulated to contain TiO₂ as an inert marker at 0.40% (as-fed basis). Pigs had free access to feed and water, and individual BW and ADFI were recorded weekly for a period of 28 d.

Individual fecal samples were collected weekly by grab sampling and stored at -20°C . Pens were scraped clean before collection. Feed samples were also collected weekly and stored at -20°C . At the conclusion of the experiment, fecal samples were allowed to thaw at room temperature and pooled within animal with a subsample collected for chemical analysis. Fecal subsamples were then oven dried in a convection oven at 65°C to constant weight. After drying, fecal subsamples were ground through a 1-mm screen before chemical analysis. Diets and fecal subsamples were subsequently analyzed for GE, DM, N, and TiO₂ according to procedures described previously. Samples of diets were also analyzed for EE, ST, ADF, NDF, and TDF according to procedures described previously.

For the growing and the finishing phase, ADG, ADFI, and G:F were calculated, and the ATTD of en-

ergy, DM, and N of each dietary treatment were determined following the procedures outlined by Oresanya et al. (2008). The NE (kcal/kg of DM) content of diets was estimated using the following equation:

$$\text{NE (kcal/kg DM)} = 0.7 \times \text{DE} + 1.61 \times \text{EE} + 0.48 \times \text{ST} - 0.91 \times \text{CP} - 0.87 \times \text{ADF},$$

where DE was the measured DE content of the diet (kcal/kg DM); values of EE, ST, CP, and ADF are expressed as grams per kilogram of DM (Noblet et al., 1994).

Statistical Analyses

For the digestion and growth trials, normality and independence of the error were verified using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). Homogeneity of the error was verified using the Levene's test of the GLM procedure. In the MIXED procedure, the repeated statement with the group option was used for a model with unequal variances. Outliers were identified using the boxplot of the UNIVARIATE procedure, and an observation was considered to be an outlier if the observed value was greater than a 3-interquartile range away from the error mean. All data were analyzed using the MIXED procedure of SAS with the individual pig as the experimental unit.

In the digestion trial, dietary treatment was considered a fixed effect. Period and pig were included in the model as random effects. Linear and quadratic effects of dietary treatments were determined. In the growth trials, the set of treatments with the constant NE were analyzed separate from the set of treatments with the declining NE. A repeated measures model with dietary treatment as fixed effect was used. The interaction of sex and dietary treatment was not significant and was excluded from the model. Block and sex were included in the model as random effects and initial BW as a covariate. Differences among treatments were determined using ANOVA, and means were separated using the least square means statement and the PDIF option with adjustment for the Tukey-Kramer test. An α value of 0.05 was used to assess significance among treatment means.

RESULTS

Digestion Trial

All pigs were successfully cannulated at the distal ileum and recovered from surgery without complications. The NDF and TDF content of the CBS used in this study was 22.74 and 25.15%, respectively. The addition of CBS increased the dietary content of NDF and TDF from 6.76 to 14.01% and 7.27 to 14.73%, respectively

Table 3. Composition (as-fed basis) of experimental diets for growing pigs¹

		Basal	Declining NE				Constant NE		
Item	CBS, %:	0	7.5	15	22.5	7.5	15	22.5	
Ingredient, %									
Ground corn		72.24	67.02	62.06	56.5	63.24	54.29	45.50	
Corn bran		—	7.50	15.00	22.50	7.50	15.00	22.50	
Soybean meal, 46.5% CP		24.00	21.75	19.30	17.54	23.50	23.00	22.29	
Soybean oil		—	—	—	—	2.00	4.00	6.00	
Limestone		1.20	1.20	1.20	1.30	1.20	1.30	1.30	
Monocalcium phosphate		1.15	1.10	1.00	0.75	1.15	1.00	1.00	
L-Lys HCl		0.18	0.19	0.20	0.19	0.18	0.18	0.18	
L-Thr		0.03	0.03	0.03	0.01	0.03	0.03	0.03	
L-Trp		—	0.01	0.01	0.01	—	—	—	
Titanium dioxide		0.40	0.40	0.40	0.40	0.40	0.40	0.40	
Vitamin premix ²		0.16	0.16	0.16	0.16	0.16	0.16	0.16	
Trace mineral premix ³		0.14	0.14	0.14	0.14	0.14	0.14	0.14	
NaCl		0.50	0.50	0.50	0.50	0.50	0.50	0.50	
Energy and nutrients ⁴									
GE, kcal/kg		3,719	3,788	3,832	3,918	3,897	4,097	4,270	
DE, kcal/kg		3,282	3,161	3,042	3,297	3,253	3,226	3,197	
NE, kcal/kg		2,387	2,301	2,218	2,133	2,387	2,388	2,389	
Ether extract, %		2.31	2.65	2.91	3.32	4.28	6.79	9.56	
Starch, %		42.97	45.68	44.72	39.78	39.59	39.05	33.80	
ADF, %		3.56	3.67	3.78	3.91	3.68	3.79	3.90	
NDF, %		9.38	10.54	11.71	12.89	10.36	11.34	12.31	
TDF, ⁵ %		10.06	10.60	11.54	13.62	10.51	12.07	12.66	
CP, %		16.8	14.1	15.3	14.1	16.9	15.7	15.9	
SID Lys,%		0.92	0.89	0.86	0.82	0.92	0.92	0.92	
Met + Cys, %		0.52	0.51	0.50	0.49	0.52	0.52	0.51	
Thr, %		0.57	0.56	0.54	0.51	0.58	0.58	0.58	
Trp, %		0.17	0.17	0.16	0.15	0.17	0.17	0.16	
Ca, %		0.75	0.74	0.71	0.71	0.75	0.76	0.76	
Bioavailable P, %		0.26	0.26	0.25	0.22	0.27	0.25	0.26	

¹CBS = corn bran with solubles (Poet Nutrition, Sioux Falls, SD). Basal = basal diet containing 0% CBS and 0% soybean oil (SBO); declining NE = diets containing 7.5, 15, or 22.5% of CBS and no SBO added; and constant NE = diets containing 7.5, 15, or 22.5% of CBS and 2, 4, or 6% of SBO.

²Provided per kilogram of complete diet: 6,614 IU vitamin A; 827 IU vitamin D; 26 IU vitamin E; 2.6 mg vitamin K; 29.8 mg niacin; 16.5 mg pantothenic acid; 5.0 mg riboflavin; and 0.023 mg vitamin B₁₂.

³Provided per kilogram of complete diet: 165 mg as Zn ZnSO₄; 165 mg Fe as FeSO₄; 39 mg Mn as MnSO₄; 17 mg Cu as CuSO₄; 0.3 mg I as Ca(IO₃)₂; and 0.3 mg Se as Na₂SeO₃.

⁴TDF = total dietary fiber and SID = standardized ileal digestible; values for SID Lys, Ca, and bioavailable P in diets were calculated from NRC (1998); values for NE of diets were calculated from Sauvant et al. (2004); all other values were analyzed.

(Table 2). Although dietary GE increased, the calculated ME and NE decreased across diets with CBS inclusion.

With the exception of Arg, which showed a quadratic decrease ($P = 0.03$), the AID of all other indispensable AA decreased linearly ($P < 0.001$) as CBS increased from 0 to 40% in the diet (Table 5). Similarly, a decrease in AID of dispensable Asp, Glu, and Tyr (linear, $P < 0.01$) was observed. A trend for a quadratic decrease in the AID of His ($P = 0.07$), Gly ($P = 0.06$), and Pro ($P = 0.08$) was also observed. The mean AID of indispensable AA decreased (linear, $P < 0.01$) whereas the mean AID of dispensable AA showed a tendency to decrease (quadratic, $P = 0.06$) as dietary fiber increased.

Results showed that the AID and ATTD of GE, DM, and CP decreased (linear, $P < 0.01$) as dietary fiber level

increased (Table 6). The AID of NDF and TDF was not affected but the ATTD digestibility of NDF and TDF declined (linear, $P < 0.01$), resulting in a linear decline ($P < 0.01$) in hindgut fermentation of NDF (19.6, to 5.9%) and TDF (21.9 to 9.7%) as dietary fiber content increased. Dietary fiber level, however, had no effect on hindgut fermentation of GE, DM, and CP.

The amount of DM, CP, NDF, and TDF reaching the terminal ileum and at the fecal level showed a linear increase ($P < 0.01$) in response to increased dietary fiber concentrations (Table 7). Similarly, the amount of GE at the terminal ileum (939 to 1,278 kcal/kg DMI) and at the fecal level (645 to 1,061 kcal/kg DMI) increased (linear, $P < 0.01$) as the dietary inclusion of fiber increased.

Table 4. Composition (as-fed basis) of experimental diets for finishing pigs¹

Item	CBS, %:	Basal	Declining NE				Constant NE		
		0	8	16	24	8	16	24	
Ingredient, %									
Ground corn		86.12	79.72	73.62	67.21	76.72	67.42	58.22	
Corn bran		—	8.00	16.00	24.00	8.00	16.00	24.00	
Soybean meal, 46.5% CP		11.00	9.50	7.60	6.00	10.40	9.70	9.00	
Soybean oil		—	—	—	—	2.00	4.00	6.00	
Limestone		0.80	0.80	0.90	1.00	0.80	0.90	0.90	
Monocalcium phosphate		0.80	0.70	0.60	0.50	0.80	0.70	0.60	
L-Lys HCl		0.15	0.15	0.15	0.15	0.15	0.15	0.15	
L-Trp		0.01	0.01	0.01	0.02	0.01	0.01	0.01	
Titanium dioxide		0.40	0.40	0.40	0.40	0.40	0.40	0.40	
Vitamin premix ²		0.11	0.11	0.11	0.11	0.11	0.11	0.11	
Trace mineral premix ³		0.11	0.11	0.11	0.11	0.11	0.11	0.11	
NaCl		0.50	0.50	0.50	0.50	0.50	0.50	0.50	
Energy and nutrients ⁴									
GE, kcal/kg		3,633	3,793	3,825	3,896	3,874	4,053	4,206	
DE, kcal/kg		3,302	3,176	3,047	2,917	3,265	3,228	3,195	
NE, kcal/kg		2,499	2,403	2,307	2,209	2,492	2,487	2,484	
Ether extract, %		2.28	3.21	3.45	4.07	4.53	6.77	9.60	
Starch, %		54.94	52.83	50.39	50.05	52.25	45.62	43.04	
ADF, %		3.12	3.27	3.40	3.55	3.24	3.36	3.49	
NDF, %		9.39	10.64	11.88	13.11	10.44	11.50	12.56	
TDF, ⁵ %		9.85	10.96	10.60	11.82	10.08	10.44	12.68	
CP, %		11.1	10.8	10.1	9.9	10.7	10.8	11.1	
SID Lys,%		0.58	0.56	0.54	0.52	0.58	0.58	0.58	
Met + Cys, %		0.41	0.40	0.39	0.39	0.40	0.40	0.40	
Thr, %		0.38	0.37	0.36	0.36	0.38	0.38	0.38	
Trp, %		0.12	0.11	0.10	0.10	0.11	0.11	0.11	
Ca, %		0.50	0.48	0.50	0.51	0.50	0.52	0.50	
Bioavailable P, %		0.19	0.18	0.17	0.17	0.20	0.19	0.18	

¹CBS = corn bran with solubles (Poet Nutrition, Sioux Falls, SD). Basal = basal diet containing 0% CBS and 0% soybean oil (SBO); declining NE = diets containing 8, 16, or 24% of CBS and no SBO added; and constant NE = diets containing 8, 16, or 24% of CBS and 2, 4, or 6% of SBO.

²Provided per kilogram of complete diet: 6,614 IU vitamin A; 827 IU vitamin D; 26 IU vitamin E; 2.6 mg vitamin K; 29.8 mg niacin; 16.5 mg pantothenic acid; 5.0 mg riboflavin; and 0.023 mg vitamin B₁₂.

³Provided per kilogram of complete diet: 165 mg Zn as ZnSO₄; 165 mg Fe as FeSO₄; 39 mg Mn as MnSO₄; 17 mg Cu as CuSO₄; 0.3 mg I as Ca(IO₃)₂; and 0.3 mg Se as Na₂SeO₃.

⁴TDF = total dietary fiber and SID = standardized ileal digestible; values for SID Lys, Ca, and bioavailable P of diets were calculated from NRC (1998); Values for NE of diets were calculated from Sauvant et al. (2004); all other values were analyzed.

Growth Trials

In growing and finishing pigs, the dietary NDF and TDF content increased with the addition of CBS. The basal diet offered to growing and finishing pigs had less GE and EE than diets containing CBS, with GE and EE slightly increasing with the increasing inclusion of CBS. The calculated NE in the set of diets with no SBO added declined with inclusion of CBS, but the calculated NE content in the set of diets with SBO added remained constant as CBS inclusion increased in the diet (Tables 3 and 4).

In each growth phase, the ATTD of DM, CP, and GE of the diet decreased (linear, $P < 0.01$) in pigs fed treatments with both increasing levels of CBS with or without constancy of NE (Table 8). The measured DE content of the set of diets formulated for declining NE,

however, was not affected ($P > 0.05$) by CBS inclusion in both growth phases, but there was a linear tendency to decrease ($P = 0.07$) in the DE content of diets fed to finishing pigs. Additionally, the determined NE content of these diets (Noblet et al., 1994) showed a linear decrease in the growing (2,382 to 2,317 kcal/kg; $P < 0.01$) and the finishing (2,552 to 2,442 kcal/kg; $P < 0.01$) phase as CBS was increased in the diets. Conversely, in both growing and finishing pigs fed diets formulated for constant NE, a linear increase ($P < 0.01$) in the dietary content of DE (3,055 to 3,391 kcal/kg in growing and 3,194 to 3,513 kcal/kg in finishing pigs) and NE (2,382 to 2,573 kcal/kg in growing and 2,552 to 2,672 kcal/kg in finishing) was observed when CBS was increased in the diet. In finishing pigs, a quadratic increase ($P < 0.01$)

Table 5. Effects of increasing dietary fiber from corn bran with solubles on apparent ileal digestibility of AA in growing pigs (digestion trial)^{1,2}

Item	CBS, %					SEM	<i>P</i> -value ³	
	0	10	20	30	40		LIN	Q
Indispensable AA, %								
Arg	83.4	77.9	80.8	79.5	80.6	1.1	0.22	0.03
His	87.0	80.8	82.4	79.0	80.5	1.7	<0.01	0.07
Ile	80.9	78.4	77.3	75.9	75.4	1.1	<0.01	0.35
Leu	88.2	86.6	85.8	84.7	84.4	0.8	<0.01	0.44
Lys	85.2	82.5	79.5	79.8	75.8	2.2	<0.01	0.92
Met	89.7	87.8	86.4	85.3	84.3	0.8	<0.01	0.43
Phe	87.6	85.7	84.6	83.3	82.6	0.9	<0.01	0.53
Thr	73.3	70.2	69.8	66.6	68.2	1.5	<0.01	0.24
Trp	83.4	82.7	81.1	78.6	75.9	1.3	<0.01	0.27
Val	80.3	77.2	76.2	74.9	74.3	1.2	<0.01	0.29
Mean	84.3	81.5	80.8	79.4	78.9	0.9	<0.01	0.28
Dispensable AA								
Ala	76.3	74.7	75.6	74.6	76.5	1.4	0.96	0.33
Asp	77.6	74.1	73.4	69.9	71.1	1.3	<0.01	0.19
Cys	65.0	62.0	62.6	60.7	65.2	2.1	0.86	0.11
Glu	86.4	83.4	83.8	81.4	82.2	0.9	<0.01	0.18
Gly	53.9	49.5	52.2	48.2	53.5	3.1	0.41	0.06
Pro	77.9	55.5	74.8	76.6	76.2	4.0	0.16	0.08
Ser	73.0	68.7	73.2	68.2	72.0	1.5	0.60	0.24
Tyr	87.4	85.8	85.2	83.8	82.8	0.8	<0.01	0.88
Mean	79.6	72.4	77.0	74.9	75.9	1.4	0.25	0.06
All AA	81.8	76.6	78.7	77.0	77.3	1.1	0.02	0.90

¹CBS = corn bran with solubles (Poet Nutrition, Sioux Falls, SD). 0 = basal diet; 10 = diet containing 90% of the basal diet and 10% of corn bran with solubles (CBS); 20 = diet containing 80% of the basal diet and 20% of CBS; 30 = diet containing 70% of the basal diet and 30% of CBS; and 40 = diet containing 60% of the basal diet and 40% CBS.

²Data are least squares means (n = 9).

³P-values for linear (Lin) and quadratic (Q) effects.

of DE and NE content was also observed as CBS increased in diets originally formulated for constant NE.

Growth performance results from growing and finishing pigs are presented in Table 9. The set of diets formulated with declining NE and fed to growing pigs showed a decrease in G:F ($P = 0.01$) from 0.46 to 0.43, with a tendency to decrease BW ($P = 0.10$) and ADG ($P = 0.06$). When declining NE diets were fed to finishing pigs, a decrease in BW (from 102.8 to 99.4 kg; $P = 0.03$), ADG (from 1.02 to 0.84 kg; $P = 0.01$), and G:F (from 0.33 to 0.28; $P < 0.01$) was observed. Average daily feed intake, daily DE intake, and daily NE intake were not affected by CBS level in diets formulated for declining NE and fed to growing and finishing pigs. In growing and finishing pigs BW, ADG, ADFI, daily DE intake, and daily NE intake were not affected ($P > 0.05$) by CBS level and constant NE. Gain to feed ratio, however, increased ($P < 0.01$) in growing pigs from 0.46 to 0.49 with dietary CBS level in diets formulated for constant NE but was not affected ($P = 0.67$) in finishing pigs.

Table 6. Effects of increasing dietary fiber from corn bran with solubles (CBS) on apparent ileal digestibility, apparent total tract digestibility, and hindgut disappearance of DM, energy, CP, NDF and total dietary fiber (TDF) in growing pigs (digestion trial)^{1,2}

Item	CBS, %					SEM	<i>P</i> -value ³	
	0	10	20	30	40		LIN	Q
Apparent ileal digestibility, %								
DM	79.8	76.1	75.7	71.9	71.2	1.1	<0.01	0.49
GE	78.8	75.1	74.6	72.5	72.2	1.3	<0.01	0.19
CP	77.9	75.5	72.4	69.2	67.9	1.5	<0.01	0.70
NDF	23.0	25.1	24.3	23.3	25.2	3.0	0.76	0.96
TDF	14.9	17.5	16.5	15.9	19.9	2.8	0.15	0.62
Apparent total tract digestibility, %								
DM	87.7	85.8	82.7	80.4	79.0	0.7	<0.01	0.33
GE	85.4	83.3	80.6	78.2	76.9	0.9	<0.01	0.36
CP	85.2	82.5	79.7	75.7	74.0	1.4	<0.01	0.87
NDF	42.6	41.6	41.9	29.3	30.5	2.3	<0.01	0.28
TDF	36.6	34.4	33.5	26.4	29.1	2.2	<0.01	0.66
Hindgut disappearance, %								
DM	7.8	9.7	7.1	8.4	7.8	1.0	0.68	0.77
GE	6.5	8.1	5.9	5.7	4.8	1.0	0.07	0.43
CP	7.4	7.0	7.5	6.4	5.9	1.9	0.54	0.79
NDF	19.6	16.5	17.8	6.4	5.5	3.5	<0.01	0.52
TDF	21.9	16.4	16.8	10.8	9.7	3.0	<0.01	0.81

¹CBS = corn bran with solubles (Poet Nutrition, Sioux Falls, SD). 0 = basal diet; 10 = diet containing 90% of the basal diet and 10% of corn bran with solubles (CBS); 20 = diet containing 80% of the basal diet and 20% of CBS; 30 = diet containing 70% of the basal diet and 30% of CBS; and 40 = diet containing 60% of the basal diet and 40% CBS.

²Data are least squares means (n = 9).

³P-values for linear (Lin) and quadratic (Q) effects.

DISCUSSION

Corn bran is composed mainly from the pericarp of the corn grain, which contains a lower concentration of ST and a greater concentration of insoluble arabinoxylans, cellulose, and lignin compared to whole corn grain (Bach Knudsen, 1997; Choct, 2002). The concentration of NDF and TDF in corn bran is, therefore, greater than corn. Because solubles remaining from the corn-ethanol distillation process were added to the corn bran, the EE content in CBS is approximately double, and the NDF or TDF content is half of previously reported values for corn bran without solubles (Sauvant et al., 2004; Anderson et al., 2012). As a result of the addition of solubles, the TDF content of CBS is also lower than the TDF content of DDGS (Urriola et al., 2010; Anderson et al., 2012). The source of CBS used in this experiment was the same and had similar chemical composition as reported previously (Anderson et al., 2012).

In the digestion and growth trials, the addition of CBS to the basal diet resulted in an increase of the dietary NDF and TDF content. In both experiments, the maximum dietary TDF content reached with CBS inclu-

Table 7. Effects of increasing dietary fiber from corn bran with solubles (CBS) on the amount (g/kg or kcal/kg of DMI) of energy, DM, CP, NDF, and total dietary fiber (TDF) in ileal effluent and feces from growing pigs fed the experimental diets^{1,2}

Item	CBS, %					SEM	<i>P</i> -value ³	
	0	10	20	30	40		LIN	Q
Ileal								
DM	205	248	246	281	293	11	<0.01	0.47
GE	939	1,103	1,140	1,246	1,278	56	<0.01	0.27
CP	40	44	49	53	55	3	<0.01	0.61
NDF	71	81	94	106	115	4	<0.01	0.86
TDF	79	85	102	117	127	3	<0.01	0.39
Total tract								
DM	132	151	182	203	218	7	<0.01	0.44
GE	645	741	872	990	1,061	39	<0.01	0.54
CP	27	31	36	42	44	3	<0.01	0.73
NDF	53	63	72	97	107	3	<0.01	0.12
TDF	59	67	81	102	113	3	<0.01	0.31

¹CBS = corn bran with solubles (Poet Nutrition, Sioux Falls, SD). 0 = basal diet; 10 = diet containing 90% of the basal diet and 10% of corn bran with solubles (CBS); 20 = diet containing 80% of the basal diet and 20% of CBS; 30 = diet containing 70% of the basal diet and 30% of CBS; and 40 = diet containing 60% of the basal diet and 40% CBS.

²Data are least squares means (n = 9).

³P-values for linear (Lin) and quadratic (Q) effects.

sion was, however, lower than the TDF content of a corn-soybean meal diet containing 30% of DDGS and fed to growing pigs (Urriola et al., 2010; Urriola and Stein, 2010). Most of the TDF in dietary treatments is insoluble because corn and CBS were the only source of dietary fiber in the digestion trial and the main source in the growth trials, and the nonstarch polysaccharides (NSP) of corn and its coproducts have been previously reported as insoluble (Bach Knudsen, 1997; Choct, 2002).

In the digestion trial, the observed increased amount of CP reaching the terminal ileum and the reduced AID of CP and most AA, resulting from the dietary increase of insoluble fiber, has been previously reported (Schulze et al., 1994; Noblet and Le Goff, 2001; Owusu-Asiedu et al., 2006). Urriola and Stein (2010) observed a decrease in AID of Lys with 30% inclusion of DDGS in a corn-soybean meal diet fed to growing pigs. The increase in CP reaching the terminal ileum and reduction of AID of most AA may be the result of a combination of an increased amount of endogenous N excretion and a decreased absorption of endogenous and exogenous N (Libao-Mercado et al., 2006).

Dietary fiber is considered an important contributor to the increase in the excretion and loss of endogenous protein (Souffrant, 1991, 2001; Moughan, 2003). Endogenous losses of AA can be classified into basal or minimum quantities of AA that are inevitably lost in all diets and specific losses influenced by diet ingredient composition (Leterme et al., 1996; Stein et al., 2007). Low AID of

Table 8. Effects of increasing dietary fiber from corn bran with solubles (CBS), in diets formulated with declining or constant NE, on apparent total tract digestibility of DM, GE, and CP and on the DE and NE content of diets fed to growing and finishing pigs^{1,2,3}

Item	CBS, ⁴ %:	Declining NE				SEM	<i>P</i> -value ⁵		Constant NE				SEM	<i>P</i> -value ⁶	
		0	7.5/8	15/16	22.5/24		LIN	Q	0	7.5/8	15/16	22.5/24		LIN	Q
Growing pigs															
ATTD of DM, ⁷ %	84.2	81.8	80.7	79.8	0.4	<0.01	0.07	84.2	84.5	80.9	80.2	0.5	<0.01	0.28	
ATTD of GE, %	82.2	79.6	78.3	77.7	0.5	<0.01	0.04	82.2	82.7	79.7	79.4	0.5	<0.01	0.41	
ATTD of CP, %	79.0	71.5	72.7	69.7	0.7	<0.01	<0.01	79.1	80.3	73.8	74.5	0.9	<0.01	0.71	
DE, kcal/kg	3,055	3,014	3,002	3,044	17	0.13	0.83	3,055	3,224	3,266	3,391	22	<0.01	0.31	
NE, ⁸ kcal/kg	2,382	2,327	2,300	2,317	13	<0.01	0.07	2,382	2,491	2,504	2,573	16	<0.01	0.23	
Finishing pigs															
ATTD of DM, %	89.9	88.0	85.9	84.2	0.5	<0.01	0.93	89.9	88.3	87.5	84.2	0.4	<0.01	0.03	
ATTD of GE, %	87.9	86.0	83.7	81.8	0.6	<0.01	0.93	87.8	86.5	86.2	83.0	0.5	<0.01	0.04	
ATTD of CP, %	84.5	80.1	75.7	72.1	1.0	<0.01	0.70	84.6	81.2	79.5	74.9	0.9	<0.01	0.38	
DE, kcal/kg	3,194	3,261	3,201	3,189	22	0.07	0.85	3,194	3,353	3,495	3,513	18	<0.01	<0.01	
NE, kcal/kg	2,552	2,536	2,465	2,442	17	<0.01	0.86	2,552	2,632	2,719	2,677	15	<0.01	<0.01	

¹CBS = corn bran with solubles (Poet Nutrition, Sioux Falls, SD), and ATTD = apparent total tract digestibility. Declining NE = diets containing CBS and no soybean oil (SBO) added; and constant NE = diets containing CBS and 2, 4, or 6% of SBO.

²Data are least squares means (n = 10).

³Dietary treatment x sex, P > 0.05.

⁴Fed diets containing 0, 7.5, 15, or 22.5% CBS to growing pigs and diets containing 0, 8, 16, or 24% CBS to finishing pigs.

⁵P-values for linear (Lin) and quadratic (Q) effects are for the effects of declining NE with CBS inclusion.

⁶P-values for Lin and Q effects are for the effects of constant NE with CBS inclusion.

⁷ATTD = Apparent total tract digestibility.

⁸Values of NE of diets were calculated from Noblet et al. (1994) and expressed as-fed basis.

some AA might reflect the effect of higher intestinal specific endogenous losses, which can increase as insoluble dietary fiber increases in the diet. Langlois et al. (1987) observed an increase in the secretion of pancreatic juice and protein after pigs were fed diets with 40% wheat bran, a source of insoluble fiber. An increased mucosa enzyme activity and mucin content has also been observed in pigs fed diets with high insoluble fiber (Hedemann et al., 2006). Leterme et al. (2000) reported an increase of ileal endogenous N losses in piglets when insoluble fiber from barley endosperm increased in the diet. The presence of insoluble fiber in the diet has also been reported to impair the AID of N (Schulze et al., 1994). Huisman et al. (1985) observed a decrease in AID of CP and most AA with the inclusion of insoluble dietary fiber from straw meal. Drying and addition of solubles to corn bran may also reduce the AID of Lys in CBS. During DDGS production, the formation of biologically unavailable Maillard reactions products from excessive heat and the addition of solubles have been previously suggested to lower AID of Lys in DDGS (Pahm et al., 2008; Stein and Shurson, 2009).

Because fiber in corn and its coproducts is mostly insoluble, and in the NDF analysis soluble carbohydrates are not included, the expected values of NDF and TDF content of ingredients and diets are relatively similar. In growing pigs, Urriola et al. (2010) reported a strong relationship between the ATTD of TDF and of NDF in corn-soybean meal diets containing 30% DDGS, a source of insoluble fiber. Corn and CBS were the only source of fiber in the dietary treatments, and a similar pattern for di-

gestibility of NDF and TDF was, therefore, expected. Results showed that insoluble fiber from corn and CBS have no effect on the ileal digestion of dietary fiber, which has also been demonstrated previously using different sources of insoluble dietary fiber (Graham et al., 1986; Urriola and Stein, 2010). For all dietary treatments, approximately 24 and 17% of the ingested NDF and TDF, respectively, was digested before the end of the ileum. Schulze et al. (1994) observed that level of insoluble fiber did not affect ileal digestibility of NDF, and 17% of ingested NDF from wheat bran was digested before the end of the ileum. Similarly, the addition of wheat bran to a basal cereal-based diet did not affect the AID of NSP, and approximately 11% of the NSP in the wheat bran containing diet were fermented before reaching the hindgut (Graham et al., 1986). Fermentation of soluble and insoluble dietary fiber in the small intestine has been previously reported by other researchers (Jørgensen et al., 1996; Urriola et al., 2010; Urriola and Stein, 2010). Because pigs do not possess the enzymes necessary to hydrolyze dietary fiber, microbial fermentation is responsible for the disappearance of dietary fiber before the end of the ileum. Results from the digestion trial indicated that ileal fermentation of dietary fiber was not affected by level of insoluble dietary fiber, indicating that microbial fermentation before the end of the ileum was not affected by the amount of substrate present. In contrast, the amount of soluble dietary fiber in the diet has been reported to affect the degree of fermentation before the end of the ileum, and the importance and extent of fermentation of dietary fiber in

Table 9. Effects of increasing dietary fiber from corn bran with solubles in diets formulated with declining or constant NE on growth performance and energy intake in growing and finishing pigs^{1,2,3}

Item	CBS, ⁴ %:	Declining NE				SEM	<i>P</i> -value	Constant NE				SEM	<i>P</i> -value
		0	7.5/8	15/16	22.5/24			0	7.5/8	15/16	22.5/24		
Growing pigs													
BW, kg		49.5	49.1	48.8	47.0	0.7	0.10	49.4	49.6	49.5	48.6	0.7	0.78
ADG, kg		1.04	1.02	1.01	0.92	0.04	0.06	1.04	1.07	1.07	1.02	0.03	0.65
G:F		0.46 ^a	0.44 ^b	0.44 ^b	0.43 ^b	0.01	0.01	0.46 ^b	0.47 ^{ab}	0.48 ^a	0.49 ^a	0.01	<0.01
ADFI, kg		2.29	2.35	2.30	2.15	0.07	0.26	2.29	2.28	2.23	2.09	0.07	0.14
DE intake, kcal/d		6,998	7,092	6,896	6,554	216	0.33	6,988	7,347	7,277	7,078	211	0.61
NE intake, kcal/d		5,456	5,474	5,285	4,990	166	0.16	5,449	5,677	5,578	5,370	163	0.56
Finishing pigs													
BW, kg		102.8 ^a	101.7 ^a	101.3 ^{ab}	99.4 ^b	0.8	0.03	103.0	103.0	102.4	102.5	0.9	0.94
ADG, kg		1.02 ^a	0.97 ^{ab}	0.94 ^{bc}	0.84 ^c	0.04	0.01	1.03	1.02	0.99	0.99	0.04	0.90
G:F		0.33 ^a	0.32 ^{ab}	0.31 ^b	0.28 ^c	0.01	<0.01	0.33	0.34	0.34	0.34	0.01	0.67
ADFI, kg		3.08	3.07	3.02	2.94	0.10	0.70	3.09	2.93	2.89	2.91	0.10	0.43
DE intake, kcal/d		9,847	9,995	9,653	9,412	293	0.53	9,888	9,846	10,113	10,278	309	0.77
NE intake, kcal/d		7,871	7,773	7,433	7,208	227	0.16	7,902	7,728	7,869	7,833	249	0.96

^{a-c}Within a row and declining or constant NE, means without a common superscript differ, $P < 0.05$.

¹CBS = corn bran with solubles (Poet Nutrition, Sioux Falls, SD). Declining NE = diets containing CBS and no soybean oil (SBO) added; and constant NE = diets containing CBS and 2, 4, or 6% of SBO.

²Data are least squares means ($n = 10$).

³Effect of week, $P < 0.05$; dietary treatment \times sex, $P > 0.05$; and dietary treatment and week, $P > 0.05$.

⁴Fed diets containing 0, 7.5, 15, or 22.5% CBS to growing pigs and diets containing 0, 8, 16, or 24% CBS to finishing pigs.

the small intestine is related directly to the proportion of soluble dietary fiber (Graham et al., 1986).

In pigs, the largest portion of ingested dietary fiber is fermented by the microorganisms of the hindgut (Noblet and Le Goff, 2001). The ATTD of NDF and TDF, however, decreased with level of inclusion of insoluble dietary fiber from corn, which agrees with previous reports that ATTD of NDF and TDF decreases after 30% DDGS is added to a basal corn–soybean meal diet (Urriola and Stein, 2010). This observation may be attributed to a low ATTD of fiber in corn bran because fiber in corn is largely insoluble and composed of cellulose and arabinoxylans, polysaccharides that are partially resistant to microbial degradation (Choct, 2002; Guillon et al., 2007). The lower degradability of dietary fiber in the hindgut, as a consequence of level of insoluble fiber in the diet, resulted in an increase in fecal output of dietary fiber. Digestibility in the hindgut is a function of hydrolysis or fermentation and digesta transit time, and a rapid passage of digesta may decrease the time that substrates are subjected to fermentation and decrease degradability in the large intestine (Morel et al., 2006; Wilfart et al., 2007a). In growing pigs, low digestibility of fiber seems mainly due to the high rate of passage when feeding fiber-rich diets (Le Goff et al., 2002), but a decrease in the microbial capacity of the hindgut to ferment the increased flow of ingested insoluble dietary fiber may have also contributed to this effect.

The amount and the physicochemical composition of dietary fiber present in the diet may also influence energy and nutrient digestion and growth performance. The observed increase in ileal and total tract amounts of GE and DM and concomitant decrease in AID and ATTD was a direct result of gradually replacing highly digestible ST in the diet with low digestible insoluble dietary fiber from CBS. Energy digestibility has been previously reported to decrease linearly with dietary NDF content (Noblet and Perez, 1993; Lindberg and Pedersen, 2003). In growing pigs, each 1% increase in NDF content of the diet reduces the energy digestibility by 0.9% (Le Goff and Noblet, 2001). Similar effects on ileal and total tract digestibility of DM have been previously reported after insoluble dietary fiber was included at the expense of a highly digestible source of carbohydrates (Newton et al., 1983; Graham et al., 1986; Schulze et al., 1994; Le Goff and Noblet, 2001; Wilfart et al., 2007b). Because fiber has an energy diluting effect in the diet, the extent of the decline in dietary energy is such that fiber fermentation may contribute little to the overall energy supply to the animal (Le Goff and Noblet, 2001; van Milgen, 2006). Energy contribution from short chain fatty acids produced during fiber fermentation in the gastrointestinal tract of the growing pig, however, maybe offset by an increase in endogenous secretions or by a reduction in the availability of other dietary nutrients so that the net contribution from fermenta-

tion of dietary fiber to the overall energy supply is close to zero (Le Goff and Noblet, 2001; van Milgen, 2006). In diets containing CBS or DDGS, the high EE content of the feedstuff may attenuate the negative effects on dietary energy supply from dietary fiber content. This advantage may be lost when DDGS is manufactured with reduced EE content, due to better extraction of EE content because of better extraction of EE from the solubles, resulting in a more concentrated fiber and lower NE content.

In the growth trials, calculated NE of diets during formulation of dietary treatments differ from NE estimated from observed DE and dietary chemical composition (Noblet et al., 1994) in growing and finishing pigs. This outcome may originate from the underestimation of the NE of CBS used for diet formulation and obtained from feed composition libraries available (Sauvant et al., 2004). Solubles added back to the corn bran are rich in EE and may increase the NE content of corn bran. The rich content of EE in CBS resulted in the dietary increase of EE with CBS level, leading to an increase of observed NE with CBS level. Dietary treatments intended for constant NE, therefore, showed an increase (191 and 120 kcal/kg for growing and finishing pigs, respectively) in the observed NE content, possibly from the underestimation of NE in CBS used during formulation.

Surprisingly, in growing and finishing pigs, ADFI was not affected by dietary treatments. In pigs under thermoneutral conditions, a decrease in energy density of the diet is commonly associated with an increase in ADFI, to compensate for required energy intake to support maintenance and growth (Henry, 1985). Energy density of the diet influences ADFI, but the absence of this adjustment when dietary energy is diluted may be the consequence of physical factors related to gut fill (Henry, 1985). Gut fill caused by excessive bulkiness of a high fiber diet may limit short-term response in feed intake when energy density is low and in some extreme cases may exert a depressive effect in feed intake. During dietary energy dilution, the ability of the pig to compensate for an increased feed intake may be enhanced, however, after a period of adaptation to a high-fiber diet (Kyriazakis and Emmans, 1995). In both growth trials, the underestimation of the NE content of CBS during formulation of dietary treatments, resulting in a greater than expected NE density in treatments with high amounts of CBS, may have explained the absence of differences in ADFI and average daily energy intake across treatments in both growing and finishing pigs.

A reduction in growth performance was expected in both growing and finishing pigs because of a decreased availability of dietary energy and AA, resulting from the previously reported negative effects of dietary fiber from corn on digestibility of energy and nutrients. In the current experiment, decreased growth performance was observed in growing and finishing pigs fed diets formulated for declining NE. In contrast, growth rate was maintained

in growing and finishing pigs fed diets formulated for constant NE and in growing pigs actually improved feed efficiency. Although observed NE increased in diets formulated to remain constant, in growing and finishing pigs the NE intake of this set of diets was similar, which validates the original intention of supplying the animal with equal amounts of usable energy, by applying the NE system. Baird et al. (1975) reported that dietary fiber content has no effect on growth performance suggesting the pig can tolerate quite a wide range of dietary fiber, provided dietary energy density is adequate. Beaulieu et al. (2009) confirmed these findings. In pigs fed constant NE diets, growth performance was maintained by an equal supply of NE from digestion and absorption of ST and lipids (especially in the high fiber diets), if availability of AA is not a limiting factor. In pigs fed diets formulated for declining NE, on the other hand, the energy from fermentation of dietary fiber did not compensate the decrease in energy supply from highly available carbohydrates replaced by insoluble dietary fiber. Additionally, in diets formulated for constant NE, dietary energy digestibility at the ileal level may have not been reduced by level of dietary fiber. This is not uncommon and has been reported in previous experiments that used different sources of insoluble dietary fiber, where a minimal effect on ileal digestibility and absorption of energy and nutrients was reported (Wang et al., 2002; Serena et al., 2008). The greater content of EE in diets with constant NE may have also reduced digesta transit time and may improve fiber degradation because high fat digesta moves slower through the intestinal tract (Cervantes-Pahm and Stein, 2008), exposing the fiber for microbial fermentation for a longer period of time.

In conclusion, results of this research indicate that increasing the amounts of insoluble and low fermentable fiber from corn reaching the hindgut may reduce the ability of growing pigs to ferment the fiber component of the diet and may also decrease the digestibility of dietary AA. In addition, a balanced supply of highly available energy in the form of ST and specially lipids overcomes the detrimental effects of increased fiber from corn on growth performance. In spite of the reduction in digestibility of energy and nutrients with insoluble and low fermentable fiber level from corn, growth performance was not affected when energy was balanced in the diet.

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